International Journal of Analytical, Experimental and Finite Element Analysis (IJAEFEA), Issue. 2, Vol. 2, June 2015.
e-ISSN: 2394-5141, p-ISSN: 2394-5133, pp 73-79

Energy Absorption Capacity of Thin Walled Circular Aluminium Sections

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***Abstract:* - In this research, capacity of thin walled circular aluminium tubes to sustain plastic deformation was tested under quasi static axial compression forces. For this purpose test was conducted in two segments, starting from the computational part, performed on finite element code ABAQUS, where the tubes of D/T ratio 7.23, 11.40, 23.61, and 24.41 and L/D ratio as 4.56, 4.23, 4.11, and 3.94 were modelled to compress them under static compression loads and observe the nature of collapse along with load carrying capacity for individual test piece while the identical test were done on compression testing machine to verify the existence of results obtained from computational analysis. Finite element code has been taken in use due to its versatility in complex problem solving skills. Tensile testing was also performed to identify the nature of aluminium material through stress strain curve, whose values were employed further in computational analysis for embedding the properties of modelled specimens. Observations of collapse modes and maximum load carrying capacity was compared at the end, both the results of computational as well as practical analysis were in found good agreement with each other. Finite element method had also proved its significance in the prediction of modes of collapse on thin walled structures**.

Index Term: -3D Modelling and simulation, Finite element analysis, Computational test, axial compression test

I. INTRODUCTION

Metallic tubes are employed at several stages of vehicle assembly among which the most common is in energy absorbers. Energy absorbers also known as shock absorbers are guided with these tubes so as to secure the vehicle from impact damages. Energy absorption capacity of metallic tubes is a significant feature which enhances safety assurance as well as act as a medium of aesthetics at certain places. In order to exhibit maximum energy absorption capacity a tube should have good stiffness and must be able to sustain plastic deformation so as to resist the kinetic energy that is exerted on to it just by occupying the position in plastic deformations under the instances of varying loading as seen by Gupta et al. [1], beside this, shapes of metallic tubes also play a vital role in the performance to sustain axial loads.

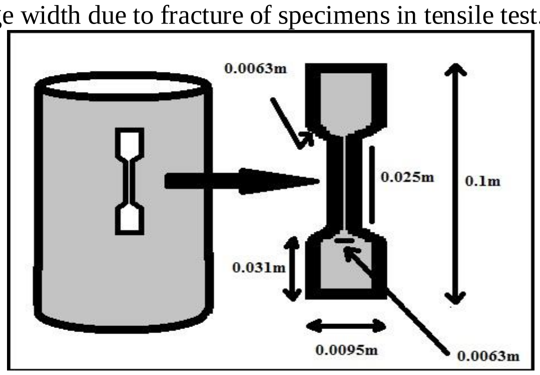
In this research thin structures of aluminium tubes were taken into consideration for testing because of the light weight of structures and properties of aluminium. Aluminium has been used in the field of energy absorption since late 30s and then it was flourished worldwide after Second World War due to scarcity of steel [2]. Selection of aluminium since then was considered perfect for survival because of its nature and characteristics of good corrosion resistance, formability and ductile nature. But choice of aluminium requires a proper aluminium alloy capable enough to survive the instances and able to convert the kinetic energy into plastic deformations which directly depends upon the material properties, displacement patterns, magnitude and application of loads on the material tested by Johnson et al. [16]. Design and development of energy absorbers concentrates on the futuristic approaches of material usage in real life constraints, as in the cases of accidents that occur due to sudden impact on vehicles which happen abruptly and lead to casualties, while in experimental cases they tend to damage the material. Loads are basically exerted in two different modes firstly static which take place in homogenous nature, and continuity throughout the experiment while second is dynamic loads which baffles the stress strain rate, as well as creates fissures in material. In this research we have concentrated on taking static loads into consideration while applying axial compression, as it would be help in obtaining finer results beside this it was also observed that force levels of dynamic forces were 10% enhanced in comparison to static loading which may deviate the results from the path [4]. Moreover, dynamic loads not only manipulate the properties of a material due to strain rate sensitivity effects but also influence the collapse patterns as observed by Karagiozova et al. [5].

Identification of the precise nature of tubes is a difficult phenomenon because of its dependency on several process parameters. Some of the parameters includes shapes of the metallic tubes which play a vital role in the performance to sustain axial loads as clarified by Xiong Zhang et al. [8] design of basic pyramid elements which was observed to be absorbing 54-93% increased capacity of energy absorption compared to the conventional tubes. Adachi et al. [9] studied the position of stiff ribs in thin walled tubes and their effects on axis-symmetric and non axis-symmetric collapses which can also be considered as the significant parameter for energy absorption of metallic tubes. This research includes varying diameter to thickness ratio 7.23, 11.40, 23.61, and 24.41 and length to diameter ratio as 4.56, 4.23, 4.11, and 3.94 for a circular tube as a test specimen. Effect of dimension and properties of material was given a significant importance in this research as it observed in the results of Shahi et al. [12] how the tailor made tubes were capable of performing efficiently

than a conventional tube. Circular tubes were taken as Zarei et al. [7] proved while testing multi design optimization technique that a circular tube has 10% higher energy absorption capacity than a square tube. Computational test were conducted on Finite Element code ABAQUS as classified by Pled et al. [6] and Kiran et al. [14] that finite element analysis has been a good approach in the process of domain discretization and it is difficult to solve the governing differential equations of material domains analytically, which were championed by finite element analysis. Simulations were performed on 3D deformable circular tube structures modelled through ABAQUS, which were put on to test under quasi static axial compression loads. An attempt has been made to comprehend the behaviour of circular aluminium tubes when subjected to quasi-static axial compression loadings between two analytical rigid plates modelled in ABAQUS and to authenticate the results similar practical experiments were also performed on compression testing machine at static test conditions avoiding the loading angles as it tends to increase the dynamic buckling of tubes as seen by Borvik et al. [3]. The results so obtained are compared and discussed further throughout the research.

II. TENSILE TESTING SPECIFICATIONS

Tensile test was conducted to obtain the properties of aluminium material used for research. Universal testing machine of 400kN capacity has been used to carry out the tensile test on rectangular specimens of aluminium drafted with gauge parameters as fillet radius of 0.0063m, thickness of 0.0008m, gauge width of 0.0063m, gauge length of 0.025m, width of grip section as 0.0095m, length of grip section as 0.031m and overall length of 0.1m, as per ASTM E8 standards and observed in [12] which are illustrated in figure 1(a) and (b). Gauge parameters are taken in consideration as it easily facilitates the necking at gauge width due to fracture of specimens in tensile test.



(a)

(b)

Figure1. Drafted test specimens for tensile testing

Beside test specimens Semi-circular fixtures were also designed, as it was difficult to grip the specimen into the conventional jaws of universal testing machine. One side of the surface of fixture was kept grooved so as to generate friction while other was semi circular to enhance the gripping. Figure2 (a) and (b) demonstrates the top and bottom design of fixtures.

(a) (b)

Figure2. Design of fixtures (a) Top surface (b) Bottom surface

Tensile test helped in obtaining the stress strain curve for aluminium material. The values of stress and strain thus obtained were converted into true stress and true strain points in order to plot true stress strain graph for aluminium material. Equation (1) and (2) are employed to convert the value of stress strain curve adopted from [11].

$$\sigma = s(1+e) \tag{1}$$

$$\epsilon = \ln(1+e) \tag{2}$$

Where,
σ - True Stress
ϵ - True Strain
s – Engineering Stress
e – Engineering Strain

Beyond the ultimate stress necking starts generating at gauge width of tensile test specimen which is illustrated in figure 3.

Figure3. Gauge width of fractures tensile test specimen

Figure 4 demonstrates the true stress strain graph plotted which is compared with a specimens graph [10] adopted to verify the accuracy of results in terms of properties for aluminium material.

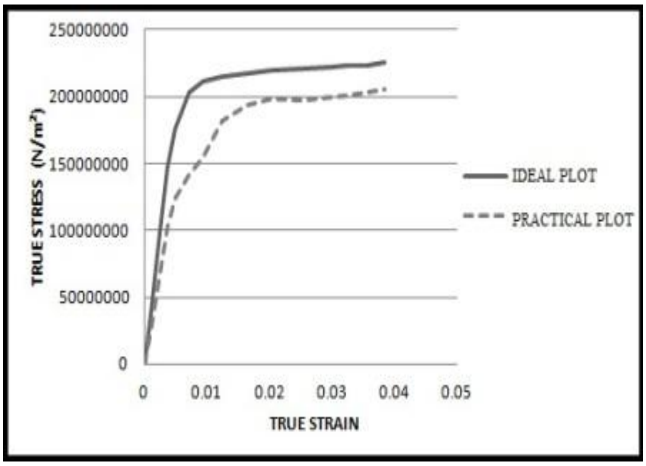


Figure4. True stress and True strain curve for Aluminium specimen

III. COMPUTATIONAL ANALYSIS

Computational test were performed to analyze the growth in modes of collapse through simulations, when a circular tube is subjected to axial compression forces. For this purpose finite element analysis was adopted to carry out the 3D simulations.

A. Finite Element Analysis

In this research finite element code ABAQUS is taken in use for 3D modelling and simulations for axial compression on circular aluminium tubes. Finite element method has vast approach to sort out complex discrete problems which consist of thousands of elements and nodes, analytically it is not possible for a human to solve. Besides this, finite element method holds well when dealing with structure analysis that's the reason it was employed in this research.

B. 3D Modelling and Simulations

Complete modelling and simulation of circular tubes was done in two segments, at first modelling was performed through different modules of ABAQUS including part which creates a 3D axis- symmetric circular tube with dimensions as specified in Table 1.

TABLE1. DIMENSIONS OF CIRCULAR TUBE FOR COMPUTATIONAL TEST

Diameter (m)	Thickness(m)	Length(m)	D/t ratio
0.02193	0.00303	0.1	7.24
0.02326	0.00204	0.1	11.4
0.02432	0.00103	0.1	23.61
0.02540	0.00102	0.1	24.81

After drafting tube, two rigid compression plates were also designed in order to facilitate compression effect on top and bottom surfaces of tube. Dimensions of plates were kept on the basis of tube specifications. Part module is then succeeded by property phase which allots several characteristics to the tube as shown in table 2, adopted from Pled et al. [6] and obtained from true stress strain curves.

TABLE2. MECHANICAL PROPERTIES ADOPTED FOR CIRCULAR TUBES

Density (Kg/m^3)	Young's Modulus (GPa)	Poisson's Ratio
2700	70	0.3

Assigning properties to the tube makes them behave alike with aluminium specimen. Assembling of the three parts was done through assembly mode which arranges the parts in a proper hierarchy so that it resembles in manner of tube compression. Further, assembly was sent for application of load on to it, in which bottom plate was kept encastre rigid while top compression plate was assigned with an axial compressive load of compression on tube, and then interaction was generated throughout the assembly. Final touch was provided through meshing the tube into fine discrete elements so as to get accurate and approximate results of simulations. Job module submits the job ready for simulation. Figure 5 demonstrates the meshed assembly of circular aluminium tube.

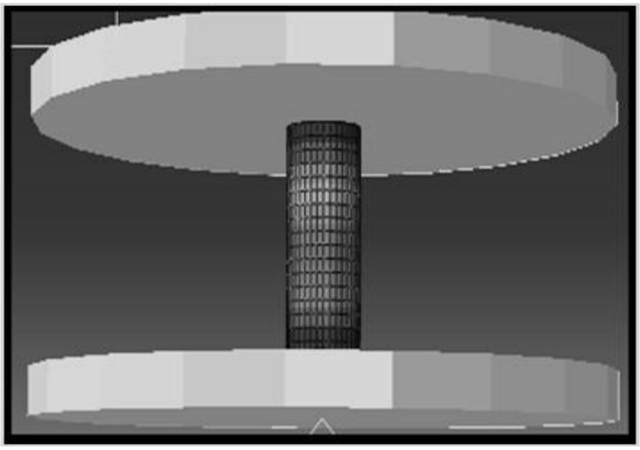


Figure5. Meshed specimen of Circular Aluminium specimen

C. Conversion Test

This study was undertaken in ABAQUS so as to identify the approximate number of divisions to be made on the thickness of 3D modelled tubes while meshing throughout the test in order to enhance their loading carrying capacity. For this purpose, different tubes of 0.1m height were designed at several mesh divisions in a gradually increasing range of 2, 3,4,5,6 and so on at a thickness of 0.001m and boundary condition for compression was assigned at upper plate up to a length of 0.09m. It was seen that tube with a two divisions on thickness was exhibiting higher load carrying capacity which eventually decreased until four numbers of divisions

then became constant throughout the process as shown in the graph of figure 6.

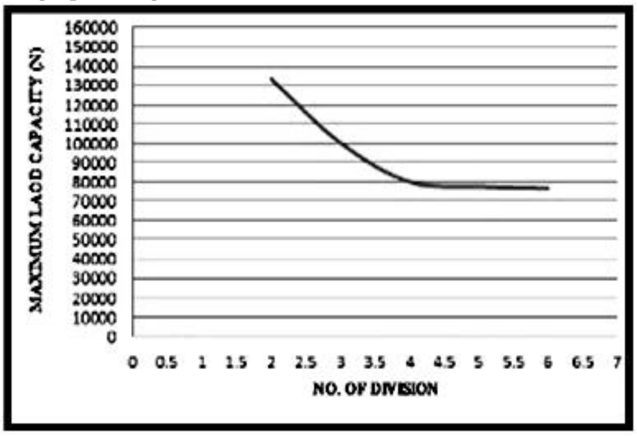


Figure6. Plot between number of Mesh divisions and Maximum load carrying capacity

Appropriate selection of division includes fine meshes along with good load carrying capacity with was observed in four numbers of divisions on thickness, so it was maintained throughout the computational analysis.

D. Methodology

Conversion study rectifies the problem of meshing the meshing. Then actual test enhances with modelling of 3D circular tubes with dimensions as specified earlier in table 1 and meshing adopted from conversion theory. Dimensions of table 1 which were in the format of D/T ratio were tested in ABAQUS under quasi static axial loading from the top platen of tubes and observations were notified for the simulations. It was seen that at the end of each compression process after complete distortion, walls of tubes were getting crushed in the form of axis-symmetric folded manner throughout the periphery as shown in figure 7.

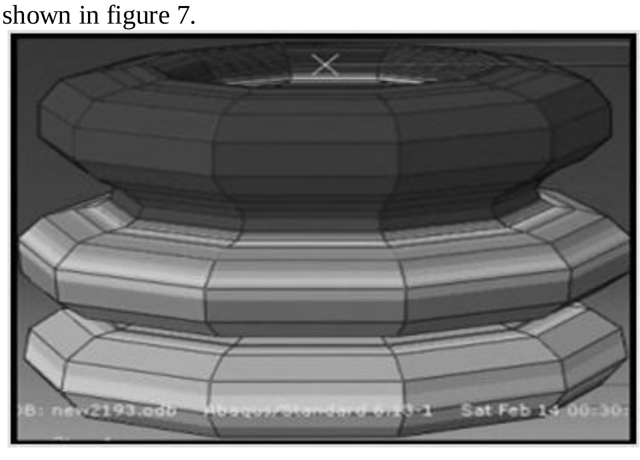


Figure7. Crushed walls of circular aluminium tube

It was crushed under crushing forces of compression forces. Load displacement curves were plotted to observe the maximum load carrying capacity among the different D/T ratios. Figure 8 demonstrates varying load carrying capacities for D/T ratios of circular tubes.

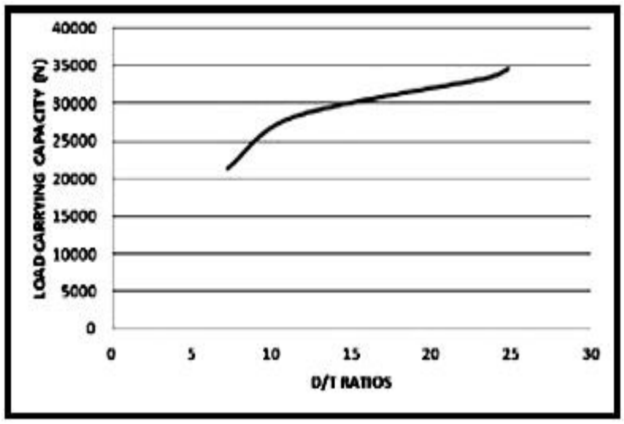


Figure8. Plot for varying D/T ratios on the basis of Maximum Load carrying capacity

The curve drawn from simulations between D/T ratios and Maximum load carrying capacity shows the variation in energy absorption of tubes as D/T ratio was linearly enhanced. From these results tube dimension having larger absorption capacity was notified as D/T ratio of 24.81. Based on these observations, identical tests were performed by taking circular tubes with similar dimensions as that of D/T ratio 24.81 but the varying parameter was kept L/D ratio, as mentioned in table 3.

TABLE3. PARAMETERS FOR L/D RATIO FOR CIRCULAR ALUMINIUM TUBES

Diameter(m)	Thickness(m)	Length(m)	L/D ratio
0.0254	0.00102	0.025	0.98
0.0254	0.00102	0.05	1.96
0.0254	0.00102	0.075	2.95
0.0254	0.00102	0.1	3.94

L/D ratios were used in the computational analysis for the purpose of observing the effect of length on load carrying capacity along with enhancing the research findings. Figure 9 demonstrates the effects of length parameter on the load carrying capacity.

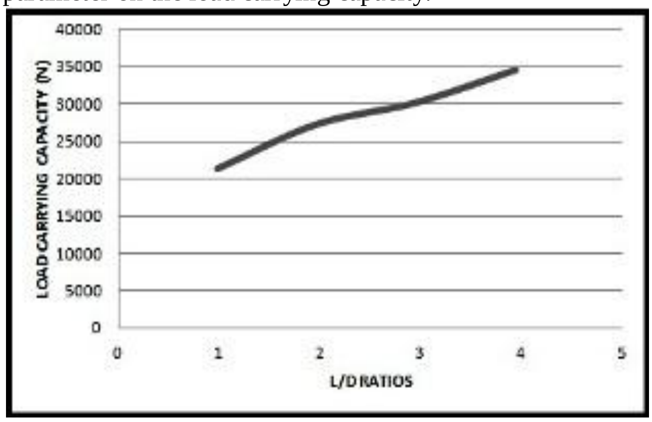
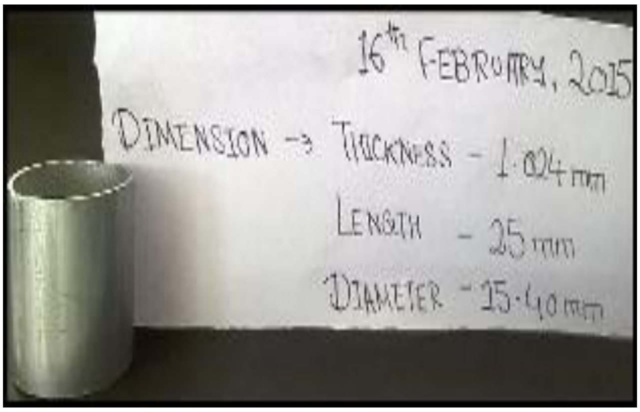


Figure9. Curve for differentiating between varying L/D ratios of circular aluminium tubes

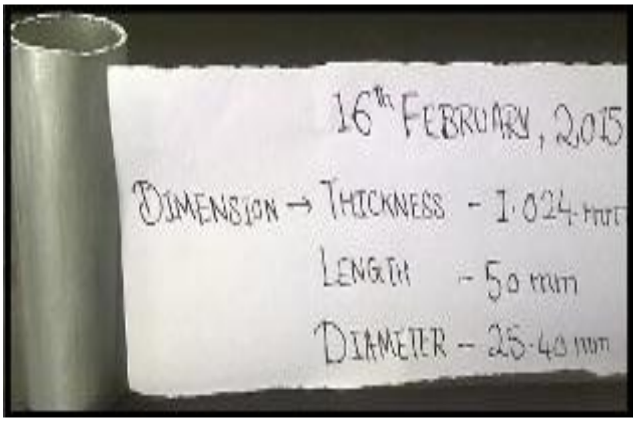
It was seen from the curves of figure 9 that change in length along with diameter tends to manipulate the capacity of energy absorption proportionally.

IV. Practical Analysis

Practical test were performed under compression testing machine of 1200kN capacity on the dimensions of circular aluminium tubes adopted from table 3 of varying L/D ratios. These tests were considered as the part of validation to the computational analysis performed on several dimensions of circular tubes. L/D ratios were taken to observe the relevance of results seen before on D/T ratio of 24.81. Figure 10 demonstrates the circular test specimens for axial compression.



(a)



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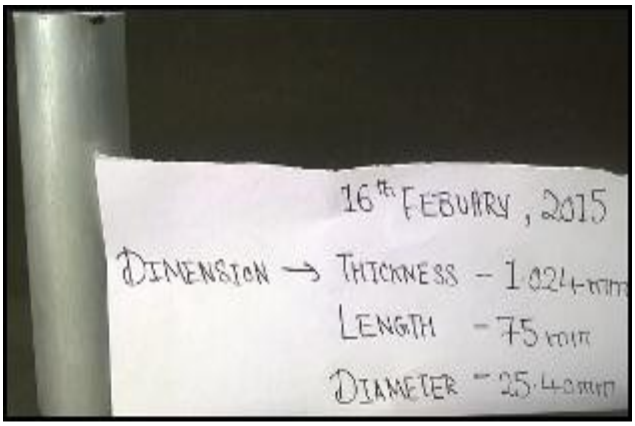
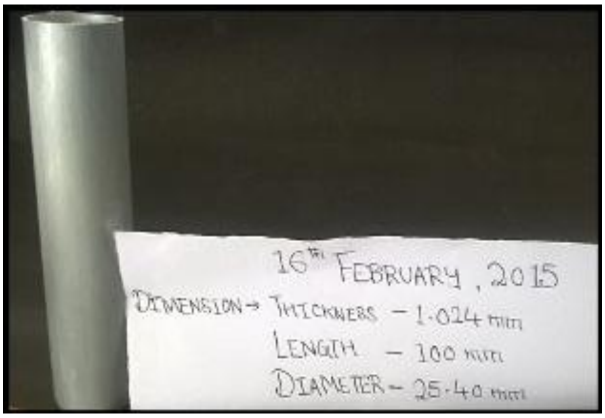


(c)



(d)

Figure10. Circular Test specimens for axial compression testing (a) For L/D ratio 0.98 (b) For L/D ratio 1.96 (c) For L/D ratio 2.95 (d) For L/D ratio 3.94

Axial compression was applied on the tubes axially avoiding oblique loadings as it tends to manipulate the mode of collapse while tubes were also inspected to neglect geometrical disorder on the cross-section as it influences the energy absorption capacity of material as observed from the results of Rouzegar et al. [15] and Eyvazian et al. [13]. Crushing forces were seen at the time of tube distortion, concentric folds were observed on the overall circumference of circular tubes. Load carrying capacity was recorded at every instant of tube crushing figure 11 demonstrates the differentiating load carrying capacity for varying L/D ratios.

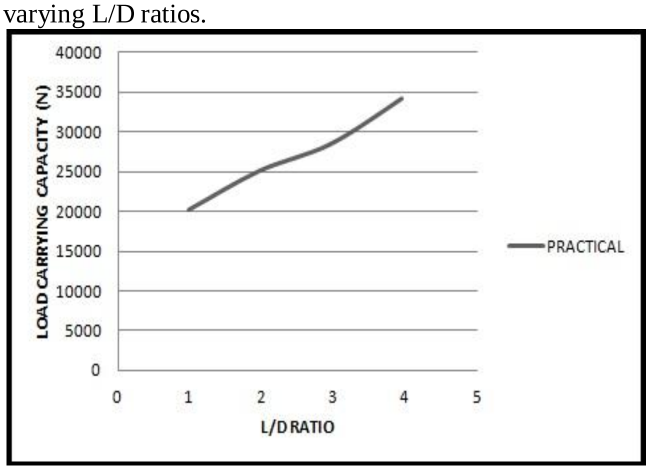


Figure11. Varying Load carrying capacity for L/D ratios

V. Result And Discussion

Observation obtained from computational and practical analysis was compared for varying L/D ratios of circular aluminium tubes. When concerning about modes of collapse axis- symmetric concertina modes of collapse were noticed in computational methods while similar crushing modes were seen in practical specimens after compression test having regular folds on the thickness of test specimens. Crushing forces were seemed to be deduced during the compression test of both the analysis. Figure 12 illustrates the comparison in collapse of tube for both methods, computational as well as practical.

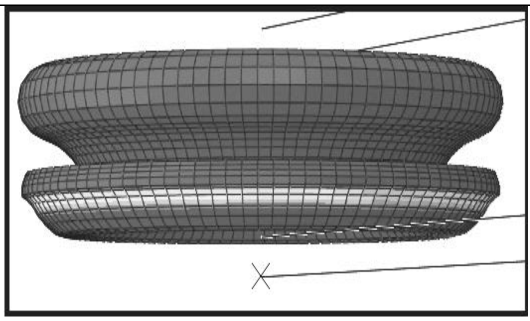
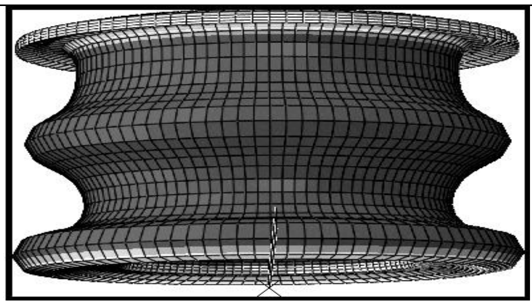
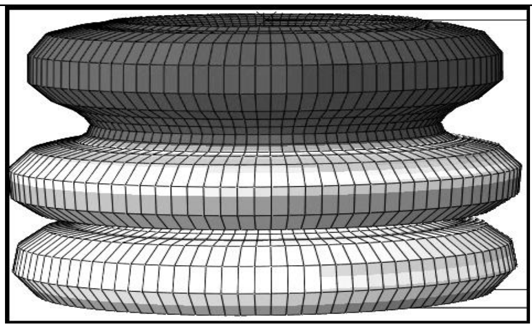
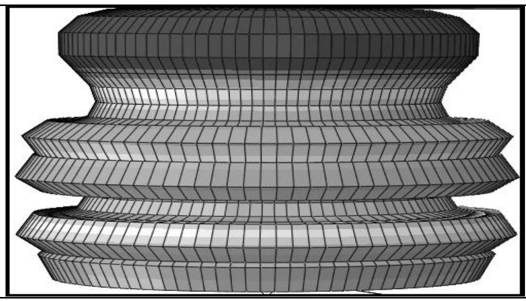
L/D RATIO	COMPUTATIONAL	PRACTICAL
0.98		
1.96		
2.95		
3.94		

Figure12. Comparison of modes of collapse between computational and practical analysis for varying L/D ratios

Load carrying capacity was the second aspect for comparison between computational and practical results, Maximum load carrying capacity was observed with the tube having L/D ratio of 3.94 which comprises of higher rate of energy absorption capacity. Computational observations notify that load carrying capacity for L/D ratio of 3.94 was 34540.6N as observed from force vs. time graph in figure 13 while similar values were seen in practical results illustrating the identical load carrying capacity as 34190.4N.

Figure 14 clearly demonstrates the coinciding results of both the analysis for common L/D ratios pertaining to circular aluminium tubes. Both the observations were found in good agreement with each other.

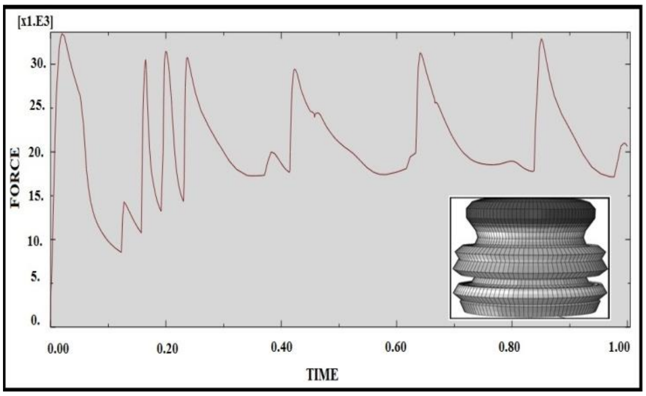


Figure13. Force vs. Time graph for L/D ratio of 3.94

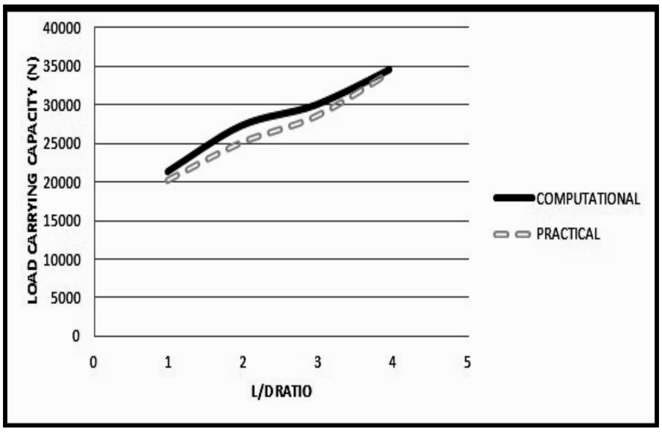


Figure14. Combined comparison of computation and practical test for L/D ratios

VI. Conclusion

Results derived from observation and comparison of tests illustrates the effect of dimensions on collapse modes and energy absorption capacity of materials. Outcome of compression tests resulted in axis- symmetric concertina mode of collapse for circular aluminium tube due to crushing loads which was dependent on the dimensions adopted. Energy absorption obtained was quite in a good agreement between computational and practical experiments as seen from figure 13 which helped in drafting the dimensions of a tube of D/T ratio 24.81 and L/D ratio of 3.94 capable of higher energy absorption which can be further used in the field of vehicle manufacturing.

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